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ARE THE LANDSCAPE TYPES WELL DEFINED FROM STATISTICAL POINT OF VIEW?

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Summary

In landscape ecology (and in geoecology) the different research groups interpret the smallest units of the landscape differently. Several ideas exist between the ecotope and the landscape unit. As far as the landscape is built up of these units and they used widely in comparative analysis, it would be proper to ask how well defined mathematically these units are and the derived systems traced from them. This determines the types of operation allowed to make among them.

In landscape ecology many types of parameters exist. To describe the landscape units and landscapes and to analyse them different data types (ratio, interval, ordinal, nominal) are available. Their usage together, however, is limited because of mathematical reasons. Several examples could be quoted as the misinterpretation of these parameters.

We have made an attempt to create statistically well defined units. We have used the following method: at first the different types of variables were subjected to cluster analysis, and than these were traced back to nominal level. Than we have created a map, based on these parameters and we have compared this map with the landscape ecological one created by traditional survey methods. Cross-tabulating these two maps we have analysed how well defined the units statistically are. The degree of similarity was different from place to place and according to the ecological characteristics of the units. The most well defined are arable lands on slopes 0-12%; the small gardens and meadows on silty soils and pasture lands.

The (regional) units of the landscape

Studies in landscape ecology may have a variety of different aims. The most common are those based on the analysis of homogeneous units or ecotopes intended to disclose the **structure** of the landscape. Such studies seek to analyze the complexity of the landscape as a means of revealing inner connections. Another approach is the **functional** analysis of the landscape. This is more of a practice-orientated approximation, dealing with the optimal utilization of a landscape and the exploration of its resources and their potential (*Leser, H. - Klink, H. J. 1988*). The motto of this kind of study is that "each landscape has its own geoecological problem". Recently, in applied landscape ecology, **process-orientated** analysis has been the focus of attention (*Mosimann, Th.1991*). In this case the landscape is frequently referred to as a system and the researchers study its functioning (i.e. landscape household).

All of these research approaches have a common feature: they require the definition of a spatial unit, though they do this in a variety of ways. Several studies have made an attempt to define this as a **statistical** unit (*e.g. Westerveld, W.G. 1984, Mezősi, G. 1986, Pohlmann, H. 1993, Saldana, A. et al 1997*).

Ecological analysis always raises the issue of regional units, and the meaning and interpretation of these regional units can be varied from study to study. The fundamental unit is the ecotope or landscape unit. The first one is very frequently used in the geo- and bioecology. In the landscape ecology and bioecology, ecotope is defined as the smallest homogenous living space. In geoecology, it is the spatial extent of abiotic geo-systems, though these are often related to biotic factors. In our opinion it would be more expedient to regard the ecotope as the smallest spatial element of the regional ecosystem including both biotic and abiotic factors. Some of the different interpretations of the smallest, but still homogeneous (in ecological sense) fundamental units (e.g. facies, ecotope, landscape unit) are compared in *Table 1*.

Dimension	scale	appr. area	Neef 1963	Haase/ Richter 1965	Iszacsen-ko 1965	Wittlesey 1954	Schmits-hüsen 1949	Zonne-veld 1972	Wieneke 1987
Topical	micro	$10\ m^2$ - $1\ km^2$	*Ökotope**	*Ökotope**	*Facies*	*Site*	*Fliese*	*ecotoop**	*Ökotope**
Choro-logical	mezo	$1\ km^2$ - $10^3\ km^2$	*Ökotop-gefüge* *Meso-chore*	*Mikro-chore (Ökotop-gefüge) Meso-chore*	*Urocsis-cse Meszt-noszty Landscape*	*Locality* *District* *(Section)*	*Fliesen-gruppen Naturra-umliche Haupein-heit*	*land facet* *land system*	*Ökotop-gefüge Mikro-chore Meso-chore*
Regional	macro	$10^4\ km^2$ - $10^5\ km^2$	*Makro-chore* *Mega-chore*	*Makro-chore*	*Okrug* *Province*	*Province* *Realm*	*Naturra-umliche Grossein-heit Natur-raumliche Region*	*land-schaft*	*Makro-chore Mikro-region Meso-region Makro-region*
Global	mega	above $10^6\ km^2$	*Geo-region*		*Zone*	*Geogra-phische Zone*			

Table 1 Geoecological and landscape ecological classification (after *Leser, H. 1991 and Huggett, J. 1995*) (*The ecotopes are the smallest units, and depending on the type of landscape their area varies from $10\ m^2$ to many km^2. They form different functional units based on structure and active processes.)

While in the English literature the "landscape unit" is more frequently used with a kind of neutral meaning, in Russian and German writings the separation of the typological elements of the landscape becomes more typical. The Hungarian scientific practice distinguishes sharply between typological (functional) and structural (topological) categories. Both are used to define landscape units, but are used independently (*Pécsi, M. 1972*). The reason for this division is probably that the main goal of many studies was meso-scale investigation in which the researchers did not face conflicts between the two concepts. A similar hierarchical system encompassing both conceptions — the ecotopes and the landscape typological classifications — can be created. The different levels are linked in the same way as far as the elements are concerned, only the point of view is different. The structure of these units is the same or similar, the biotic, chemical and physical properties are comparable, the ecological processes are alike, and their size is typical as well.

Undoubtedly some of these elements exist in reality (i.e. ecotope); others are results of some kind of synthesis or standardization (i.e. typological elements - agrarian landscape in lowland position covered by chernozem). In practice, the following questions arise: How can these elements be separated and in which case are they considered as diverse? To answer these questions, we can use distinctive characteristics of sand features, which are related to scale, dimension, and complexity. There are however difficulties in analyzing these characteristics statistically. Some types do not meet the requirements of commonly used statistical tests. We can find statistical mistakess in several geoecological investigations: for example a typical error is that some parameter categories (i.e. land use categories) are described quantitatively and then analyzed statistically. Unfortunately at many cases these categories do not meet the mathematical requirements of statistical analysis. In the following, therefore, we try to collect and present satisfactory methods for achieving correct statistical analysis.

Parameters in landscape analysis

Two problems arise with respect to the parameters used in statistical analysis of spatial units.The *first problem* is that they can be very different, limiting their ability to be used to study widely. In the geoecology three characteristic parameter types are used. The nominal type of parameter data gives information only about whether an element is a member of a set or not (i.e. soil type, land use, vegetation type). Of course these nominal parameters we used can be numbers as well, but in such case they are suitable just for identification. The values of the second type of parameter give a sequence (an ordinal), or it is possible to determinate the interval into which they fall (interval variable). In case of individual value for each interval in some respect will refer to the sequence of the characterized data. In the geoecology the variable of interval types is often derived back to the ordinal type. Variables of interval type are e.g. slope angle, grain size distribution. Derived values of ordinal type are e.g. slope categories, mechanical soil composition. Pure ordinal type of variables exist as well, like NDVI-value calculated from the satellite data or the fertility classes of soils. The parameters of the third group are the result of such measurements, which have an absolute "0" point and numbers that are rational to each other. Therefore, these kinds of variables are called ratio type of values. These parameters are very often produced by conventional measurements, like the amount of precipitation, the data of soil chemical analysis, elevation etc. The classification of the variables can be modified by considering whether they describe point-like or spatial data: for example the proportion type of slope angle data, measured on points, are interpreted as ordinal type of slope category in the spatial analysis.

Therefore, we worked with very different types of data in our geoecological investigations. But there are considerable reservations to use, the different types of data should not be treated in the same database. For example we can not make statistical analysis using nominal (i.e. vegetation type) and interval variables (i.e. slope exposure) in the same time; or we can not give numerical values for the vegetation types and analyze them together with the interval variables, because of the statistical rules. This is irregular and it gives false results. Unfortunately several false analysis (factor and coherence analysis) occur in the geoecology.

The *second problem* is how to integrate the great amount of data used in geoecological analysis. Often only groups of so-called "key-parameters" are analyzed (usually just a small portion of the originally used parameters) and these are used to make generalizations about the entire database (*Westerveld, W. G. 1984, Mezősi, G. 1986*). The only problem is that the determination of key-parameters requires the statistical analysis of the entire database in advance of the ecological one. Though, if we have to use different parameters because of the spatial and temporal variances, the key parameters will not mean too much help. The question is how to integrate all types of data in the ecological analysis.

There are two solutions to this problem in geoecology. The first is to use integrated categories such as ecotopes or other typological landscape units from the beginning of the analysis. The difficulty here is that, as noted above, the definition of these units varies somewhat from study to study (see Leser, H., 1991, or Naveh, Z. - Liebermann, A. S. 1984) and scientists may group the same units into different classes using different methods and approaches. The real trouble is that the borders and limitations of the integrated units vary considerably depending on their position in the hierarchy of the ecological system being considered. That is, the extent of a single geoecological process or element can be drawn as a homogenous unit at a particular scale with a well-defined size and border (*Mosimann, Th., 1990*). These units however may lose their homogeneity when viewed at a different scale from another level in the ecological hierarchy. The possibility exists, however, to use statistical methods to decide whether and under what conditions to draw borders around homogenous units when viewed from different levels of a hierarchy.

The second solution is to build the analysis stepwise from single parameters, and decide on the method of integrating the parameters as they are combined. Various methods for weighting and categorizing the parameters can be used. The basis of this method is holistic environmental observation. The problem is that one can never be sure about how to interpret the results nor whether appropriate statistical operations have been performed throughout the analysis. However, this method is very much in keeping with the ideas of the German landscape ecological surveying using 1: 25,000 scale maps (*Leser, H. - Klink, H. J. 1988*). Though, they summarize the apparently neutral potentials and functions, like agroecologial potential or the summary of runoff-regulating function (*Fig. 1*). As a matter of fact the question is how to create a new map using the available ordinal or scalar (continuous numerical) maps. In this case the new map consists of nominal variables, which were created by the qualification of the former maps.

Methods of the analysis and its results

Our investigation was carried out on a Hungarian test area in the Bodony Basin of the Mátra Mountains. In this basin a geoecological survey have been carried out (*Mezősi, G. - Rakonczai, J. 1997*). All the important data and maps were available for the analysis, including the map of the landscape units constructed on the basis of traditional methods. There were several ways to create statistically well-defined units. The one employed here was to create unit-groups based on similarity. The statistical method will be compared to the survey method.

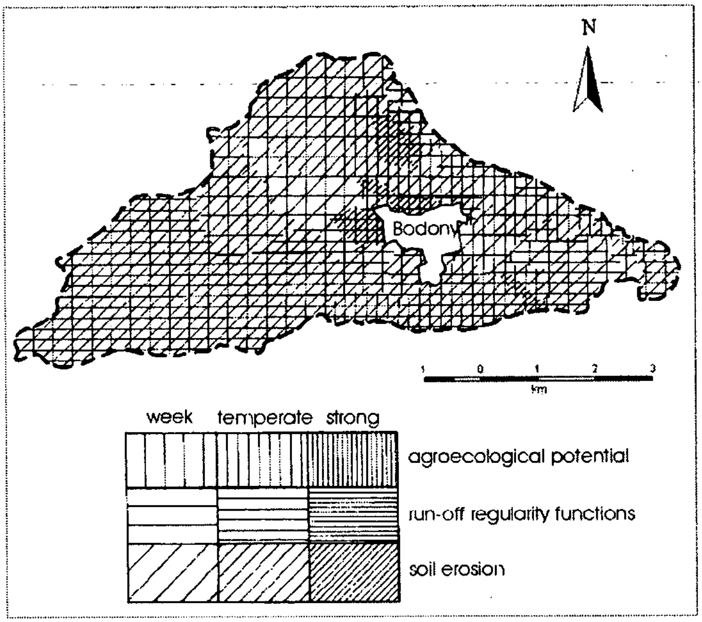

Figure 1 Landscape ecological map created by combining the agroecological potential, soil erosion and run-off regulation function (Bodony Basin, Mátra Mts., N-Hungary)

The basis idea of the method applied was the reduction of all variables to the nominal level (*Fig. 2*). However, this reduction was not done in one single step, because much information would be lost. The following method was used instead. First, cluster analysis was performed on all ratio variables (*Fig. 3*) to reduce them to ordinal level. We have made another cluster analysis on this database and on the other ordinal type of data, creating a cluster map, which is on the nominal level now. It carries the ordinal and ratio type of information, and besides these, we have lots of nominal data (i.e. land use) independent from the above mentioned ones. The difficulty was that on the nominal level the cluster analysis could not be carried out in the traditional way. In order make a cluster analysis some criteria have to be completed, but in our case the data do not have normal distribution.

We searched for such a method for separating the units, which avoids the problem of weighting parameters among each other's. Namely, the parameters used in practice do not have the same importance (Solncev Rule; *Mezősi, G. 1986*).

This kind of weighted is originated from the order of the maps, as we use them, one after the other, for drawing borders. For example, we started our research with the land use or the slope category or the soil-type map — depending on the topography —, and then the borders of the chosen map will be dissected further on, using other new parameters. We will come up against the problem of distinguishing ecotopes, both if we use weighted or integrated units (see 2. chapter) or the parameter method.

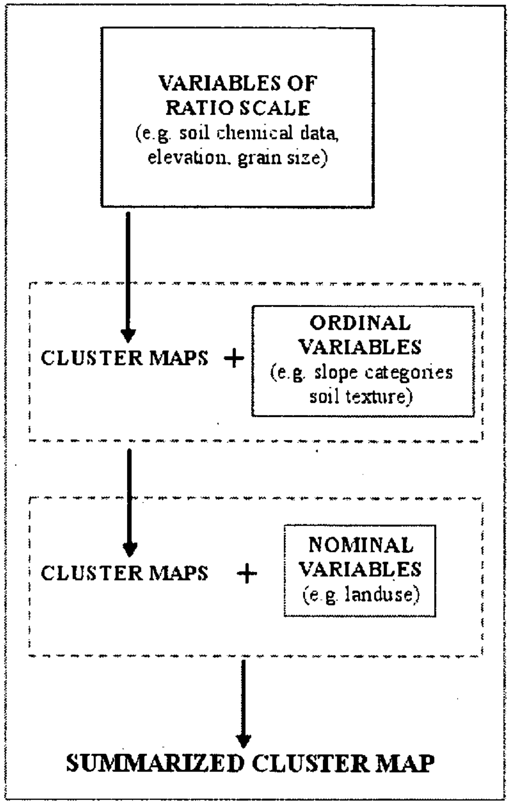

Figure 2 The steps of the analysis

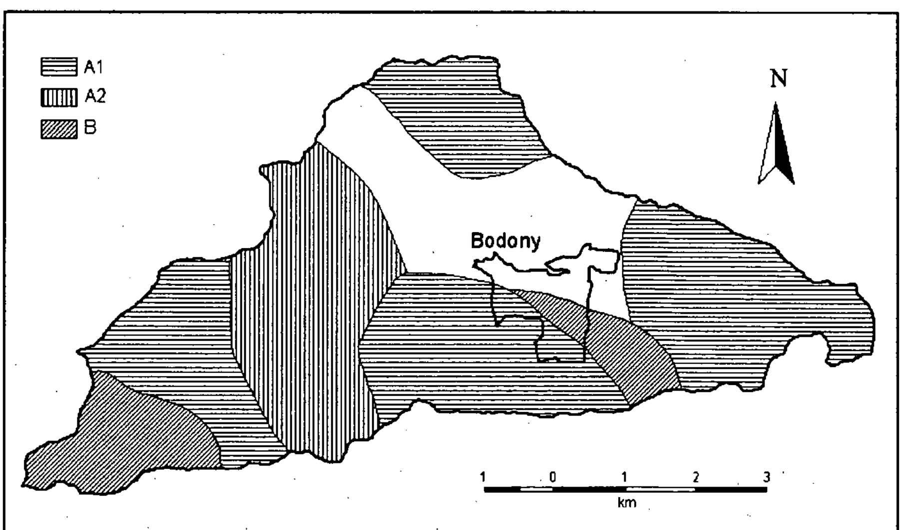

Figure 3 A cluster map of the soil chemical data (ratio level) of the test site on ordinal level

Using the nominal data, borders were defined by search for spatial, rather statistical clustering. To do this we superimposed a 123x242 grid (cell size is 50x50 m) over the study area using Arc/Info 7.0.3. software. The result, however, is different depending on the applied method, but we have got very low number clusters, which consisted only few elements. For example we obtained only five classes of more than 10 pixels (58, 37, 24, 12 and 10 pixels). But these clusters were only a small portion of the 14,360 pixels — cover the watershed — in the grid. As we saw above, on this level all the advances disappeared which were useful on the ratio level. Therefore, we have had no chance to explore new relationships, because only few parameters (7) were used and only two ordinal cluster maps with too many classes.

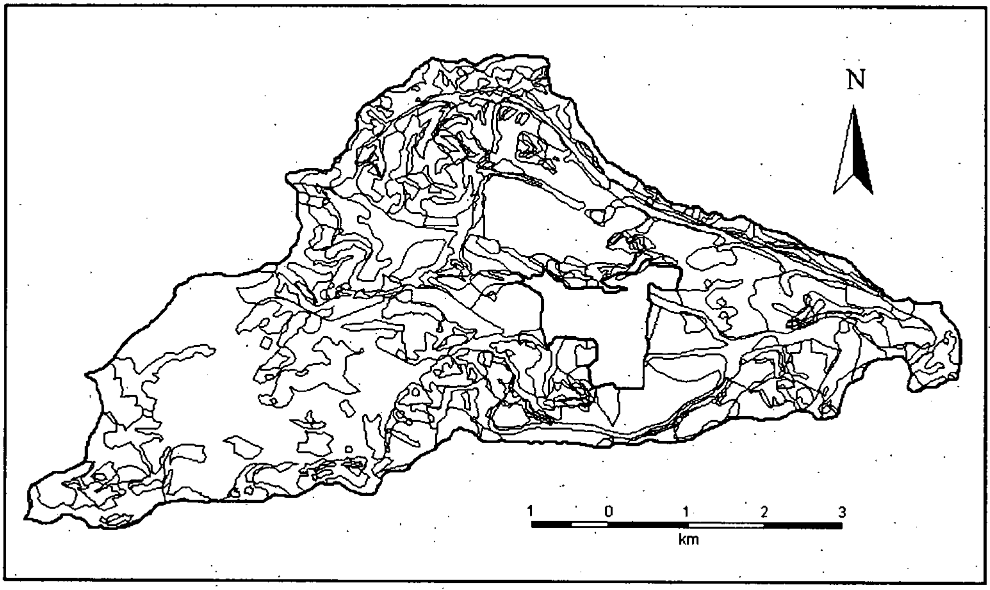

Figure 4 Statistical units of the landscape

Since our aim was to explore the topology, it seemed easier to analyze all the input data on the nominal level. We aimed not to do any weighted during their selection, thought the selection itself is a kind of weighted as far as we have had to consider whether to use a certain parameter or not. The analysis made on the ratio and ordinal level helped us to decide which parameter should we take into the analysis. As an attempt we created two parameter sets. Into the first one three parameters fall: soil texture, land use and slope categories; the first one carried the information of the ratio level, the second one represented the nominal, while the slope categories carried the ordinal information. The second parameter set included soil texture, land use, slope categories, thickness of the tilth, soil pH, vegetation type, exposure and diversity of vegetation.

The maps of the different sets of variables were overlaid and compared using the polygon-intersection method available in Arc/Info software. The first, smaller set of variables yielded the following results. The 9 categories of the soil texture map produced 70 polygons, the 8 categories of the land use map produced 52 polygons and the 5 categories of the slope categories produced 316. The intersection of the resulting maps produced 1130 polygons (*Fig. 4*) each of which is homogenous from the standpoint of some combination of the three variables. Altogether there were 15 distinct combinations, 7 of which together covered more than 80% of the area (*Table 2*). The remainder of the area differed only by soil texture, the first variable (*Fig. 5*), not by land use or slope. This remained the case even after the number of slope categories was increased using a more detailed scale.

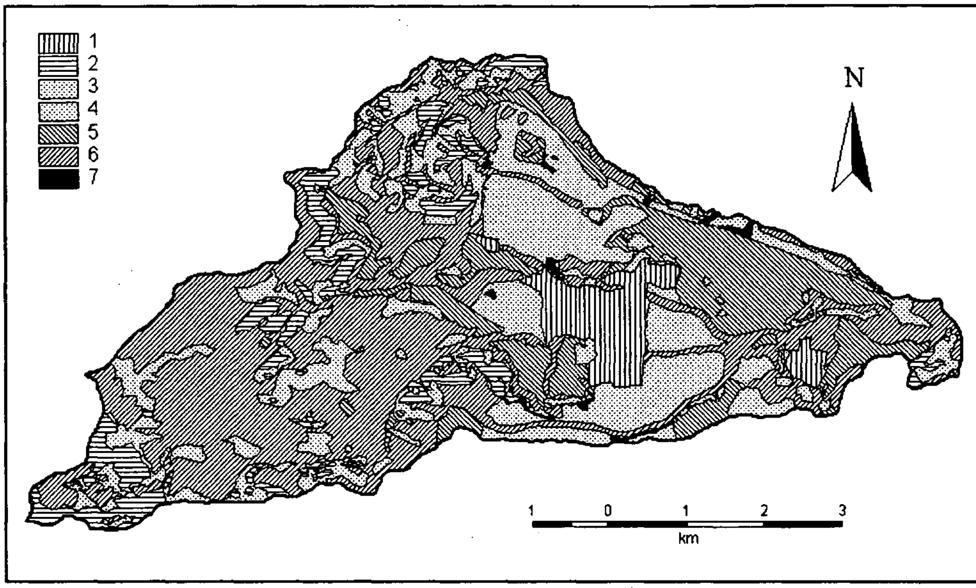

Figure 5 Polygons resulted by the intersection of landuse, soil texture and slope category maps (**1**: 0-12% slope angle, downtown, lake, quarry, loamy silt; **2**: steeper slope than 17%, meadow, forest, silt; **3**: 12-17% slope angle, meadow, pasture land, grove, clay; **4**: 0-12% slope angle, arable land, silt; **5**: 0-12% slope angle, meadow, pasture land, clay, heavy clay; **6**: 0-12% slope angle, forest, sandy silt; **7**: steeper slope than 12%, arable land, clay)

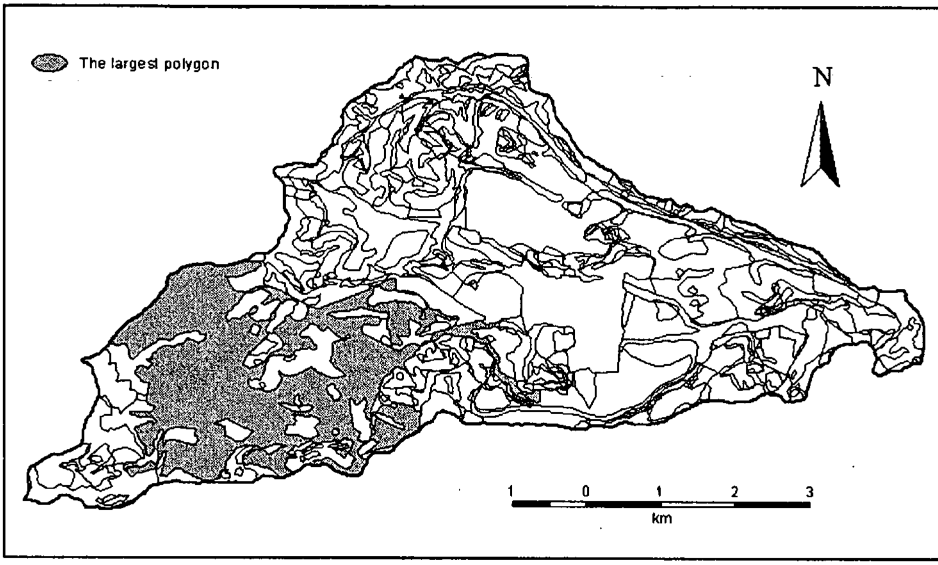

Figure 6 The largest polygon produced by the intersection

From the ecological point of view, we think it is very informative to examine the characteristics of the spatial clusters. The total number of polygons gives an overall sense of the mosaic-like structure of a landscape, their average size provides a sense of the relevant scale, and the largest polygons (*Fig. 6*) provide a sense of the most homogenous characteristics.

It is worthwhile to compare these results (*Fig. 5*) with a traditional geoecological map of the same area produced by Mezősi and Rakonczai (*1997*) (*Fig. 7*). The comparison was made by cross-tabulation and can be considered from two perspectives. The first is whether the statistically defined categories match those of the traditional ecological map, and second, the degree of this correspondence. Those categories that coincide by more than 10% are listed in *Table 2*.

The table indicates that only a few of the categories (1, 4, 6, 12, 14 and 15) of the two maps coincide by as much as 75-85 %. Closer examination reveals that survey categories 1 and 15 are both contained in statistical category 1, survey categories 4 and 6 in statistical category 6, survey category 12 in statistical category 5, and survey category 14 in statistical category 4. There seems to be no relationship between the size of the categories and the degree of correspondence between the two maps. Survey categories 1 and 15 are urban areas with the ecological characteristic of settlements. Their distinctive characteristics and high spatial concentration can be seen in the statistical map as well. Survey categories 12 and 14 are also distinctive and not unexpectedly appear as different statistical categories.

Category 12 includes xerophilous steppe meadows, whereas category 14 contains arable land. The meadows are typically found along ridges whereas the arable land usually occupies the middle part of the drainage area, at mid-elevation, and on relative low slopes. It was not surprising that survey category 4 also appeared strongly in the statistical map since it corresponds to swampy and marshy stream valleys covered by hygrophyte forests. At first it is difficult to explain why the small survey category of Scotch pine forest falls into the same category as swampy and marshy land. Forestry data indicates however that the Scotch pine forest plantations were based on economic (easy accessibility, low relative relief), rather than ecological considerations.

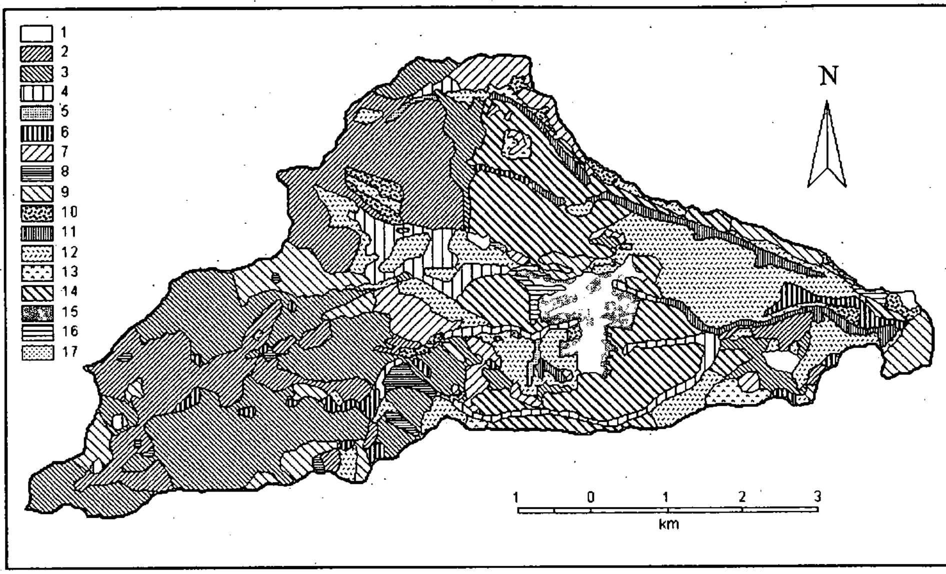

Figure 7 Landscape ecological map of the model area made by field survey
1 - settlement, quarry; 2 -mesophyl deciduous and mixed forest on sandy soil, on slopes steeper than 12%; 3 - xerophyl groves, bushy associations on slopes steeper than 17 %, on silty soil, pasture land; 4 - swamp, hydrophyl forest on silty soils, meadow; 5 - hydrophyl groves; 6 - Scotch pine plantation on clay; 7 - deciduous forest plantation on silt, on foothills; 8 - young deciduous forest plantation on sandy silt, in valleys; 9 - planted mixed forest mainly on sandy soils, on slopes steeper than 17%, east exposition; 10 - bushy associations on hills, on silty soils; 11 - vegetation of eutrophic waters and springs, pasture land; 12 - calciphylous meadows on loamy silt; 13 - ruderal and weedy meadows on loamy silt; 14 - arable land on slopes 0-12%, on silty soils; 15 - small gardens, parks; 16 - orchard, fruit plantations; 17 - vineyard and hop plantations on slopes 12-17%, on loamy silt

These results of this comparison indicate that six of geoecological categories (*Fig. 5*), representing almost 40% of the area, are homogenous and well-defined. Of the remainder, geoecological categories 2, 3, and 9 are non-homogenous, composite categories that are definitely not well-defined.

Viewed from another perspective, *Table 2* also shows that statistical category 6 contains a great number of the survey categories found on the traditional geoecological map. This implies that this category is overclassified under the traditional survey method, that is divided into more categories as are supported by the present statistical analysis. Part of the difference may be accounted for by the fact that the survey was based on field investigation in which a uniform geoecological category was further subdivided by vegetation type.

Categories of the landscape ecological survey's map (see their description on Fig.7.)	Number of pixels covering each category of the landscape ecological map	The percentage of pixels in each category of the landscape ecological map that coincide with the categories of the statistical map (Fig. 5.) (only those values above 10% are listed)		
1.	319	90 % (1)		
2.	2379	53 % (6) *	27 % (3)	19 % (2)
3.	3268	66 % (6)	19 % (3)	13 % (2)
4.	687	82 % (6)		
5.	49	67 % (6)	14 % (5)	12 % (3)
6.	330	79 % (6)		
7.	648	65 % (6)	20 % (3)	13 % (2)
8.	121	48 % (6)	28 % (3)	23 % (2)
9.	944	53 % (6)	28 % (2)	17 % (3)
10.	274	71 % (6)	27 % (3)	
11.	376	63 % (5)	33 % (6)	
12.	2165	85 % (5)		
13.	163	60 % (4)	36 % (6)	
14.	2315	88 % (4)		
15.	217	81 % (1)	15 % (4)	
16.	92	67 % (1)	25 % (4)	
17.	19	63 % (1)	21 % (3)	

Table 2 The correspondence between the landscape ecological maps made by land survey and by statistical analysis (* 53 % of the 2379 pixels belongs to category 6 of the statistical map, 27% to category 3, and 19% to category 2)

It is worthwhile to compare the statistical map categories with the borders of the geoecological map (*Fig.1*). We found, as expected, few areas of correspondence between the traditional survey and the statistical maps. This was not surprising because the parameters used to produce the geoecological maps (such as run-off regulating function, soil erosion) are interrelated and determined primarily by relief. Still, this should not be viewed as a flaw since the geoecological map contains much information of practical value. It means only that the statistical map delineated borders using strict criteria. The geoecological map was compiled to reveal, as possible, hidden or obscured attributes of the landscape units. Such subtle gradations appear in the statistical map only when characteristics like soil erosion are determined by cross-classifying a wide range of factors. Such subtleties can be noted, for example, in statistical category 6 which corresponds to areas of moderate run-off regulation function, poor agroecological potential and moderate soil erosion and in statistical category 4 which corresponds to heavy soil erosion, moderate agroecological potential and moderate run-off regulating attributes.

The most important warning indicated by our findings is that, in landscape ecological research, special attention must be paid to the selection and analysis of variables and their statistical type. Their use must be planned consciously to serve the aims of the study and must take into account the statistical rules that govern their use. But methods exist for meeting these rules of spatial statistics in the analysis of many types of complex landscape ecological maps.

Conclusions

1. In some cases, the landscape units used in landscape ecology are not well defined mathematically and statistically. That is, from time to time, the landscape units cannot be differentiated one from another strictly in terms of their underlying statistical distributions. Sometimes too, the underlying statistical distributions are used incorrectly in defining the landscape units.

2. There are nonetheless several statistically correct solutions for delimiting the landscape units if needed. This does not mean that they are the only units that should be employed. There are other such landscapes units that are used in practice and derived from other principles such as the weighed of selected variables. These may work well if they are designed carefully. The variables that are included must be selected and controlled with care. Statistics can be an effective tool of analysis, but it cannot be used automatically to solve all problems.

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